BIOTREATED CONVENTIONAL CONCRETE AND CDW-CONCRETE BY USE OF MICROBIAL MIXED CULTURES BIOPRODUCTS

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Abstract
Cracks form in all concrete constructions shortening the life of concrete elements, particularly in exposed concrete. They provide a path for transport of moisture, chlorides, and various other deleterious substances. The aim of this study was to assess the protection and consolidation effect of eco-friendly healing biotreatments on water absorption of conventional and recycled concrete, with 50% substitution of natural coarse aggregate by CDW aggregate. Concrete were treated with bioproducts obtained using waste biomass from a microbial mixed culture process for polyhydroxyalkanoates production. Results showed that the reference samples, with application of tap water, presented an increase in water drop permeability, being the absorption time shorter than in the control (untreated) samples. The biotreatment with the non-sonicated bioproduct increased significantly the water absorption time, more evident in conventional concrete samples than in recycled ones. In the case of the sonicated bioproducts, the behaviour was similar for both types of concrete specimens, but the healing effect was higher. When the biotreatment was performed with three applications, the healing effect was not so effective. This observation may be associated with the formation of a hydrophobic film of organic material from the bioproduct, which detached from the concrete surface after outdoors exposure.

1. Introduction

The quality of concrete surface plays an important role in the concrete service life [1], particularly in exposed concrete. Its quality is impacted by the water/cement ratio of the fresh concrete [2] and affects spreading processes but also hardened concrete properties [3-6]. That is even more important in the case of concrete with recycled aggregates. Due to phenomena such as the wall effect [7], contact with formworks [8] or segregation [9], the exterior layer of exposed concrete often has a different composition from the internal one and its porosity is higher than in the core of the concrete element [10]. Several studies have tested the surface healing effect of organic and inorganic treatments on cement-based materials [11,12], showing improvements on permeability, resistance to moisture diffusion and filling of surface cracks and voids. Leung et al. [13] tested neat epoxy and neat silane as well as epoxy/organoclay and silane/organoclay nanocomposites and stated that the incorporation of organoclay into silane could improve its resistance to moisture diffusion. Pigino et al. [14] applied ethyl silicate by brushing onto the surface of concrete, penetrating up to a depth of about 3-5 mm into the concrete, induced a substantial decrease in water absorption, despite the low quantity of the absorbed product. Amidi and Wang [15] tested other types of surface treatments, using calcium carbonate deposition by hydrolysis of dimethyl carbonate (DMC) to fill the surface cracks and voids of concrete elements. A reduction in water absorption was achieved. Sodium silicate has also been used [16,17].
The search for a suitable bioproduct compatible with the existing cementitious substrate and able to improve the concrete surface quality by biotreatment of incipient cracks and porous structure may be an appropriate technique. Healing, helping the external repair, decreasing maintenance costs of aged concrete structures and increasing sustainability in the construction industry would be some of the advantages of this technology.

2. Materials and methods

Conventional and recycled concrete samples were prepared to assess the protection and consolidation effect of an eco-friendly healing biotreatments on water absorption. For the manufacture of the concrete mixtures, the following materials were employed. Commercially available Portland blended cement (CEM III/A 42.5 N/SR) was conformed to the Spanish [18-19] and European [20] standards. Natural aggregates presented a siliceous nature and complied with the requirements of the EHE-08 [21] and EN 12620+A1 [22]. Recycled mixed aggregates (RMA) were obtained through a mechanical treatment of construction and demolition wastes (CDW) in a recycling plant located in the Autonomous Community of Madrid (Spain). The composition of the RMA, determined according to EN 933-11 [23], is presented in Tab. 1. Physical and mechanical properties of RMA and natural aggregates such as D/d ratio [24], fines content [24], flakiness index [25], Los Angeles coefficient [26], were within the suitable parameters established by EHE-08 [21] for the concrete manufacture. Nevertheless, results obtained for RMA water absorption [27] showed a greater variation compared to the natural aggregates. The presence of attached mortar and ceramic materials in the recycled aggregates caused a significant water absorption, higher than the one of the natural aggregates. The use of aggregates with high water absorption could result in a workability drawback. Consequently, the RMA were pre-saturated: a technique that showed to be a suitable method to manufacture inexpensive recycled concrete with low strength requirements and maintain a suitable workability [28]. Tab. 2 shows the detailed composition of the different raw components used in the manufacture of the conventional concrete (CC) and recycled concrete (RC). The w/c ratio and f_{ck} of both concretes is 0.5 and 25 MPa, respectively.

Table 1: Non-floating components of recycled aggregates.

Component	% (w/w)
Unbound aggregates (natural aggregates without cement mortar attached)	44.1
Ceramics (bricks, tiles, stoneware and sanitary ware, …)	33.6
Concrete and mortar (natural aggregates with cement mortar attached)	17.5
Asphalt	0.4
Glass	0.8
Gypsum	3.5
Other impurities (wood, paper, metals, plastic, …)	0.2

Table 2: Mix composition per cubic metre of conventional and recycled concrete.

Material	CC	RC
Water (l)	165	155
Cement (kg)	333	313
Sand 0/4 mm (kg)	103	97
Sand 0/5 mm (kg)	470	442
Gravel 4/10 mm (kg)	516	242
Gravel 6/12 mm (kg)	172	81
RMA 4/20 mm (kg)	0	323

The test samples were cubes cut from concrete specimens that were molded, and had a cut surface with 50 mm x 50 mm. The bioproducts used as healing agents were obtained using waste biomass from a microbial mixed culture (MMC) for polyhydroxyalkanoates production using pine wood bio-oil as substrate. MMC cell walls were disrupted by sonication (MMC-P_S) or not (MMC-P). Samples were treated with 2 mL of each bioproduct suspensions by using a pipette, covering the top surface. Half of the samples were biotreated with a single application, whereas on the other half, three applications were made (one application every 24 h).The effect of each bioproduct on surface treatment was evaluated and compared with untreated samples (control) and treated with the same volume of tap water (reference).

For each biotreatment and concrete, three samples were tested. The test room conditions were 20±2°C and 40±5% relative humidity (RH). Two days after the last application, the bio-healing capacity was assessed by water-drop absorption test in the air, in order to simulate real conditions. This test allows evaluating the permeability variation of the biotreated surfaces by monitoring the time required to absorb a water drop under open air conditions. The test was video recorded and the absorption time was then defined for each concrete, number of applications and treatment. After this test the samples were placed outdoors for natural aging.

3. Results and discussion

Figure 1 shows the treated samples. When the treatment included three applications, a layer of organic material from the bioproduct deposited on the surface of the concrete samples, changing its color, and the healing effect decreased. After 1 month in outdoors exposure the samples were visually observed, and the layer was no longer visualized: it was washed off or, in case of three applications of the bioproducts, it cracked and separated from the concrete surface without spotting (treated samples looked like control and reference samples, without the brownish layer).

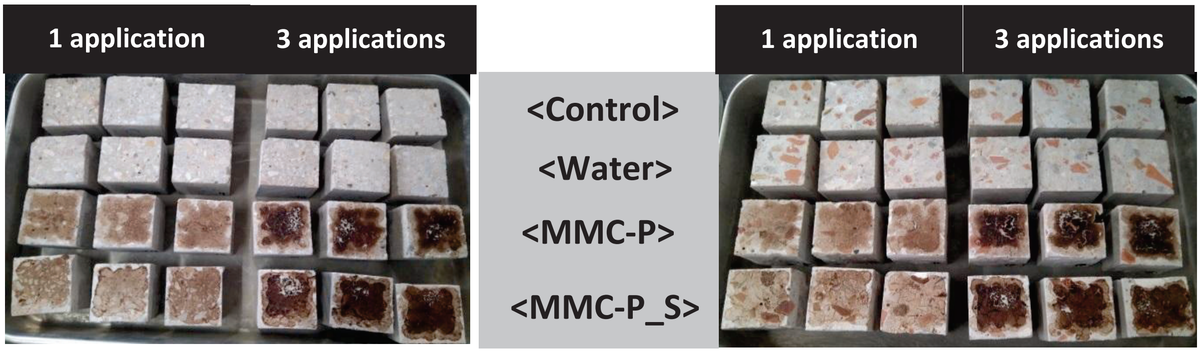

Figure 1: Conventional concrete (left) and recycled concrete (right) samples after treatment.

Figure 2 shows the time of water drop absorption for each biotreated concrete samples, the control (untreated) and the reference (with water application) samples.

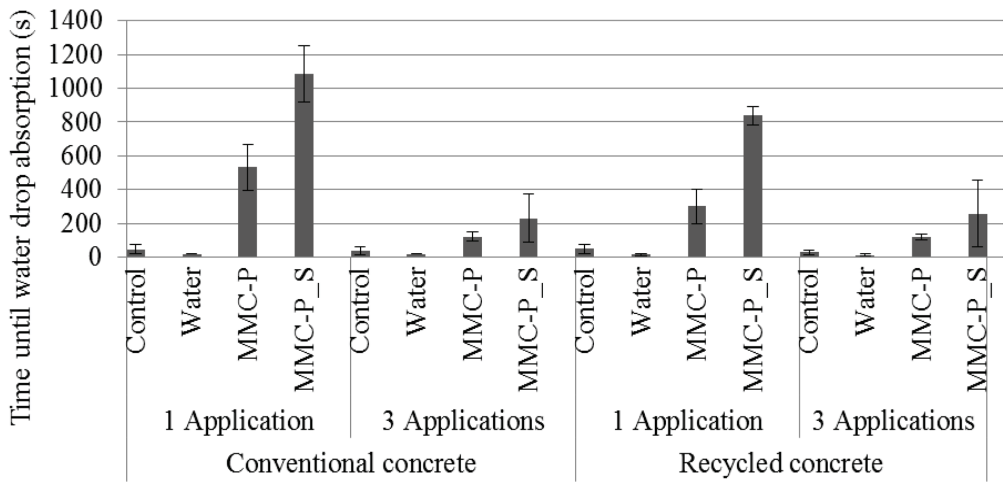

Figure 2: Results of water drop absorption test.

Results have shown that the reference concrete, with tap water, presented an increase in water drop permeability, being the absorption time shorter than in the control concrete in all cases. The biotreatment MMC-P increased the water absorption time significantly, more evident in

conventional concrete than in recycled one. In the case of the sonicated bioproducts (MMC-P_S), the behavior was similar regarding the different kinds of concrete, but the healing effect was even higher.
A comparison of results of the biotreatments with studies from other researchers is presented in Tab. 3. In the short term, the good efficiency of the biotreatments tested in the present study is clearly evident. Further studies will allow to justify this effect and if it will be durable.

Table 3: Water ingress decrease due to concrete surface treatments.

Study	Type concrete	Treatment	Reduction (%)
Woo et al. [11] - permeability	With PVA Fibers	Neat silane and silane/clay nanocomposite	29-57
Chandra et al. [12] - water absorption	Portland	Extract of cactus	83
Present - water drop ingress in comparison with control	Portland	MMC-P - 1 application	996
		MMC-P_S - 1 application	2130
	With CDW	MMC-P - 1 application	521
		MMC-P_S - 1 application	1622

4. Conclusion

The biotreatments with bioproducts from a microbial mixed culture for polyhydroxyalkanoates production process produced a decrease of the permeability on both conventional and recycled concrete. Besides, the sonicated bioproduct achieved a greater healing effect when compared with the non-sonicated MMC one. Multiple applications of biotreatment cause the formation of a hydrophobic film of organic material from the bioproduct, which detached from the concrete surface, cracking with time passed even between applications and decreasing the healing effect. Therefore, a single application of the sonicated MMC bioproduct was the most efficient tested biotreatment to increase concrete durability to water access.

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